out-of-the-way plant. It has an organisation which is not represented in the European flora. The family of thistles, and their allies the knapweeds (represented in our gardens by the ladies blue bottle), all of which are common wayside plants, exhibit excitable movements which, although of a very different kind from those we have just described, have, like them, to do with the visits of insects for the purpose of fertilisation. We will now throw on the screen a single fertile floret of *Centaurea Cyanus* (Fig. 5). The large diagram shows the same floret deprived of its corolla. Its axis is occupied by the style, surrounded by its tube of anthers. Below, the anther-filaments expand into a kind of cage, and again approach one another, when they are united with the tube of the corolla. At the moment that the anthers arrive at maturity these filaments are very excitable. When one of them is touched, it contracts and draws the style towards itself. Immediately afterwards the excitatory effect spreads to the others, all five arches becoming straight, and applying themselves closely to the style. A similar effect is produced by an induction shock. [The structure described was projected on the screen; on passing an induction current through it, the mode of contraction of the filaments was seen.]

The mechanism of Centaurea has been studied by many plant physiologists, particularly by Prof. Ferdinand Cohn of Breslau, and more recently with great completeness by Prof. Pfeffer. It has in this respect a greater interest than any other—that the shortening of these filaments in response to excitation strikingly resembles muscular contraction. You have here a structure in the form of a flattened cylinder which resembles many muscles in form, the length of which is diminished by about a sixth on excitation. This superficial resemblance between the two actions makes it the more easy to appreciate the differences.

Let me draw your attention to the diagram of an experiment made last year, which was intended to illustrate the nature of muscular contraction, and particularly to show that when a muscle contracts, it does not diminish in volume. The first difference between muscle and plant is a difference in the degree of shortening. A muscle shortens by something like a third of its length, the anther filament only by a sixth. But it is much more important to notice that in contracting, the filaments do not retain their volume. In shortening they broaden, but the broadening is scarcely measurable; hence they must necessarily diminish in bulk, and this shrinkage takes place, as Pfeffer has shown, exactly in the same manner as that in which the excitable cushion of Mimosa shrinks, namely by the discharge of liquid from its cells.

We are now in a position to study more closely the question to which I referred a few minutes ago—How do the cells discharge their contents? The structure of the filament of Centaurea, from its extreme simplicity, is a better subject of investigation with reference to this question, than any other. Each filament is a ribbon consisting of (1) a single fibro-vascular bundle, (2) delicate cells of regular cylindrical form, (3) an epidermis of somewhat thick-walled cells. [Microscopical preparations were shown.] In Mimosa we saw that the epidermis and vascular bundle took only a passive part in the production of the motion. Here, the part they play is even less important. Everything depends on the parenchyma, which, when excited, shrinks by discharging its water. Pfeffer proved this by cutting off the anther tube from the filaments, and then observing that on excitation a drop collected on the cut surface, which was reabsorbed as the filament again became arched. It is obvious that if the whole parenchyma discharges its liquid, each cell must do the same, for it is made up entirely of cells. To understand how each cell acts, we have only to consider its structure. Each consists of two parts—an external sac or vesicle, which is of cellulose, and, so long as the cell is in the natural or unexcited state, *over-distended*, so that, by virtue of its elasticity, it presses on the contents with considerable force; and secondly, of an internal more actively living membrane of protoplasm, of which the mechanical function is, so long as it is in its active condition, to charge itself fuller and fuller with liquid—the limit to further distension being the elastic envelope in which it is inclosed. In this way the two (the elastic envelope and the protoplasmic lining) are constantly in antagonism, the tendency of the former being towards discharge, that of the latter towards charge. This being so, our explanation of the effect of excitation on the individual cell amounts to this—that the envelope undergoes no change whatever, but that the protoplasm lining suddenly loses its water-absorbing power, so that the elastic force of the envelope at once comes into play and squeezes out the cell-contents. Consequently, although here, as everywhere, the protoplasm is the seat of the primary change, the mechanical agent of the motion is not the protoplasm, but the elastic envelope in which it is inclosed.

(*To be continued.*)

ELECTRIC LIGHTING BY INCANDESCENCE[1]

SPEAKING in this place on electric light, I can neither forget nor forbear to mention, as inseparably associated with the subject and with the Royal Institution, the familiar, illustrious, names of Davy and Faraday. It was in connection with this institution that, eighty years ago, the first electric light experiments were made by Davy, and it was also in connection with this Institution that, forty years later, the foundations of the methods, by means of which electric lighting has been made useful, were strongly laid by Faraday.

I do not propose to describe at any length the method of Davy, I must, however, describe it slightly, if only to make clear the difference between it and the newer method which I wish more particularly to bring under your notice.

The method of Davy consists, as almost all of you know, in producing electrically a stream of white-hot gas between two pieces of carbon.

When electric light is produced in this manner, the conditions which surround the process are such as render it impossible to obtain a small light with proportionally small expenditure of power. In order to sustain the arc in a state approaching stability, a high electromotive force and a strong current are necessary; in fact, such electromotive force and such current as correspond to the production of a luminous centre of at least several hundred candle-power. When an attempt is made to produce a smaller centre of light by the employment of a proportionally small amount of electrical energy, the mechanical difficulties of maintaining a stable arc, and the diminution in the amount of light (far beyond the diminished power employed), puts a stop to reduction at a point at which much too large a light is produced for common purposes.

The often-repeated question, "Will electricity supersede gas?" could be promptly answered if we were confined to this method of producing electric light; and for the simple reason that it is impossible, by this method, to produce individual lights of moderate power.

The electric arc does very well for street lighting, as you all know from what is to be seen in the City. It also does very well for the illumination of such large inclosed spaces as railway stations; but it is totally unsuited for domestic lighting, and for nine-tenths of the other purposes for which artificial light is required. If electricity is to compete successfully with gas in the general field of artificial lighting, it is necessary to find some other means of obtaining light through its agency than that with which we have hitherto been familiar. Our hope centres in the method—I will not say, the *new* method—but the method which until within the last few years has not been applied with entire success, but which, within a recent period, has been rendered perfectly practicable—I mean the method of producing light *by electrical incandescence.*

The fate of electricity as an agent for the production of artificial light in substitution for gas, depends greatly on the success or non-success of this method; for it is the only one yet discovered which adapts itself with anything like completeness to all the purposes for which artificial lighting is required.

If we are able to produce light *economically* through the medium of *electrical incandescence*, in small quantities, or in large quantities, as it may be required, and at a cost not exceeding the cost of the same amount of gas-light, then there can be little doubt—there can, I think, be *no* doubt—that in such a form, electric light has a great future before it. I propose, therefore, to explain the principle of this method of *lighting by incandescence* to show *how it can be applied*, and to discuss the question of *its cost.*

When an electrical current traverses a conducting wire, a certain amount of *resistance* is opposed to the passage of the current. One of the effects of this conflict of forces is the development of heat. The amount of heat so developed depends on the nature of the wire—on its length and thickness, and on the strength of the current which it carries. If the wire be thin and the current strong, the heat developed in it may be so great as to raise it to a white heat.

[1] Lecture delivered at the Royal Institution of Great Britain, March 10, 1882, by Joseph W. Swan, Sir Frederick Bramwell, F.R.S., vice-president, in the chair.

The experiment I have just shown illustrates the principle of electric lighting by incandescence, which is briefly this—that a *state of white heat may be produced in a continuous solid conductor by passing a sufficiently strong electrical current through it.*

A principle, the importance of which cannot well be overestimated, underlies this method of producing light electrically—namely, the principle of *divisibility.* By means of electric incandescence it is possible to produce exceedingly small centres of light, even so small as the light of a single candle; and with no greater expenditure of power in proportion to the light produced, than is involved in the maintenance of light-centres 10 or 100 times greater. Given a certain kind of wire, for example a platinum wire, the 100th of an inch in diameter, a certain quantity of current would make this wire white-hot whatever its length. If in one case the wire were one inch long and in another case ten inches long, the same current passing through these two pieces of similar wire, would heat both to precisely the same temperature. But in order to force the same current through the ten times longer piece, ten times the electromotive force, or, if I may be allowed the expression, electrical pressure, is required, and exactly ten times the amount of energy would be expended in producing this increased electro-motive force.

Considering, therefore, the proportion between power applied and light produced, there is neither gain nor loss in heating these different lengths of wire. In the case of the longer wire, as it had ten times the extent of surface, ten times more light was radiated from it than from the shorter wire, and that is exactly equivalent to the proportional amount of power absorbed. It is therefore evident that *whether a short piece of wire or a long piece is electrically heated, the amount of light produced is exactly proportional to the power expended in producing it.*

This is extremely important; for not only does it make it possible to produce a small light where a small light is required, without having to pay for it at a higher rate than for a larger light, but it gives also the great advantage of obtaining *equal distribution* of light. As the illuminating effect of light is inversely as the square of the distance of its source, it follows that where a large space is to be lighted, if the lighting is accomplished by means of centres of light of great power, a much larger total quantity of light has to be employed, in order to make the spaces remotest from these centres sufficiently light, than would be required if the illumination of the space were obtained by numerous smaller lights equally distributed.

In order to practically apply the principle of producing light by the incandescence of an electrically heated continuous solid conductor, it is necessary to select for the light-giving body a material which offers a considerable *resistance* to the passage of the electric current, and which is also capable of bearing an exceedingly high temperature without undergoing fusion or other change.

As an illustration of the difference that exists among different substances in respect of *resistance* to the flow of an electric current, and consequent tendency to become heated in the act of electrical transmission, here is a wire formed in alternate sections of platinum and silver; the wire is perfectly uniform in diameter, and when I pass an electric current through it, although the current is uniform in every part, yet, as you see, the wire is not uniformly hot, but white-hot only in parts. The white-hot sections are platinum, the dark sections are silver. Platinum offers a higher degree of resistance to the passage of the electric current than silver, and in consequence of this, more heat is developed in the platinum than in the silver sections.

The high electrical resistance of platinum, and its high melting-point, mark it out as one of the most likely of the metals to be useful in the construction of incandescent lamps. When platinum is mixed with 10 or 20 per cent. of iridium, an alloy is formed, which has a much higher melting-point than platinum; and many attempts have been made to employ this alloy in electric lamps. But these attempts have not been successful, chiefly because, high as is the melting-point of iridio-platinum, it is not high enough to allow of its being heated to a degree that would yield a sufficiently large return in light for energy expended. Before an economical temperature is reached, iridio-platinum wire slowly volatilises and breaks. This is a fatal fault, because *in obtaining light by incandescence there is the greatest imaginable advantage in being able to heat the incandescing body to an extremely high temperature.* I will illustrate this by experiment.

Here is a glass bulb containing a filament of carbon. When I pass through the filament *one unit* of current, light equal to *two candles* is produced. If now I increase the current by *one-half*, making it *one unit and a half*, the limit is increased to *thirty candles*, or thereabout, so that for this one-half increase of current (which involves nearly a *doubling of the energy* expended), *fifteen times more light* is produced.

It will readily be understood from what I have shown that it is essential to economy that the incandescing material should be able to bear an enormous temperature without fusion. We know of no metal that fulfils this requirement; but there is a non-metallic substance which does so in an eminent degree, and which also possesses another quality, that of *low conductivity.* The substance is carbon. In attempting to utilise carbon for the purpose in question, there are several serious practical difficulties to be overcome. There is, in the first place, the mechanical difficulty arising from its intractability. Carbon, as we commonly know it, is a brittle and non-elastic substance, possessing neither ductility nor plasticity to favour its being shaped suitably for use in an electric lamp. Yet, in order to render it serviceable for this purpose, it is necessary to form it into a slender filament, which must possess sufficient strength and elasticity to allow of its being firmly attached to conducting-wires, and to prevent its breaking. If heated white hot in the air, carbon burns away; and therefore means must be found for preventing its combustion. It must either be placed in an atmosphere of some inert gas or in a vacuum.

During the last forty years, spasmodic efforts have from time to time been made to grapple with the many difficulties which surround the use of carbon as the wick of an electric lamp. It is only within the last three or four years that these difficulties can be said to have been surmounted. It is now found that carbon can be produced in the form of straight or bent filaments of extreme thinness, and possessing a great degree of elasticity and strength. Such filaments can be produced in various ways—by the carbonisation of paper, thread, and fibrous woods and grasses. Excellent carbon filaments can be produced from the bamboo, and also from cotton thread treated with sulphuric acid. The sulphuric acid treatment effects a change in the cotton thread similar to that which is effected in paper in the process of making parchment paper. In carbonising these materials, it is of course necessary to preserve them from contact with the air. This is done by surrounding them with charcoal.

Here is an example of a carbon filament produced from parchmentised cotton thread. The filament is not more than the ·01 of an inch in diameter, and yet a length of three inches, having therefore a surface of nearly the one-tenth of an inch, gives a light of twenty candles when made incandescent to a moderate degree.

I have said, that, in order to preserve these slender carbon filaments from combustion, they must be placed in a vacuum; and experience has shown that if the filaments are to be durable, the vacuum must be exceptionally good. One of the chief causes of failure of the earlier attempts to utilise the incandescence of carbon, was the imperfection of the vacua in which the white-hot filaments were placed; and the success which has recently been obtained is in great measure due to the production of a better vacuum in the lamps.

In the primitive lamps, the glass shade or globe which enclosed the carbon filament was large, and usually had screw joints, with leather or india-rubber washers. The vacuum was made either by filling the lamp with mercury, and then running the mercury out so as to leave a vacuum like that at the upper end of a barometer, or the air was exhausted by a common air pump. The invention of the mercury pump by Dr. Sprengel, and the publication of the delicate and beautiful experiments of Mr. Crookes in connection with the radiometer, revealed the conditions under which a really high vacuum could be produced, and in fact gave quite a new meaning to the word vacuum. It was evident that the old incandescent lamp experiments had not been made under suitable conditions as to vacuum; and that before condemning the use of carbon, its durability in a really high vacuum required still to be tested. This idea having occurred to me, I communicated it to Mr. Stearn, who was working on the subject of high vacua, and asked his co-operation in a course of experiments having for their object to ascertain whether a carbon filament produced by the carbonisation of paper, and made incandescent in a high vacuum was durable. After much experimenting we arrived at the conclusion that *when a well-formed carbon filament is firmly connected with conducting wires, and placed in a hermeti-*

cally sealed glass ball, perfectly exhausted, the filament suffers no apparent change even when heated to an extreme degree of whiteness. This result was reached in 1878. It has since then become clearly evident that Mr. Edison had the same idea and reached the same conclusion as Mr. Stearn and myself.

A necessary condition of the higher vacuum was the simplification of the lamp. In its construction there must be as little as possible of *any* material, and there must be none of such material as could occlude gas, which being eventually given out would spoil the vacuum. There must besides be no joints except those made by the glass-blower.

Therefore, naturally and per force of circumstances, the incandescent carbon lamp took the most elementary form, resolving itself into a *simple bulb, pierced by two platinum wires supporting a filament of carbon.* Probably the first lamp, having this elementary character, ever publicly exhibited, was shown in operation at a meeting of the Literary and Philosophical Society of Newcastle in February, 1879. The vacuum had been produced by Mr. Stearn by means of an improved Sprengel pump of his invention.

Blackening of the lamp glass, and speedy breaking of the carbons, had been such invariable accompaniments of the old conditions of imperfect vacua, and of imperfect contact between carbon and conducting wires, as to have led to the conclusion that the carbon was volatilised. But under the new conditions these faults entirely disappeared; and carefully conducted experiments have shown that well-made lamps are quite serviceable after more than a thousand hours' continual use.

Here are some specimens of the latest and most perfected forms of lamp. The mode of attaching the filament to the conducting wires by means of a tiny tube of platinum, and also the improved form of the lamp, are due to the skill of Mr. Gimmingham.

The lamp is easily attached and detached from the socket which connects it with the conducting wires; and can be adapted to a great variety of fittings, and these may be provided with switches or taps for lighting or extinguishing the lamps. I have here a lamp fitted especially for use in mines. The current may be supplied either through main wires from a dynamo-electrical machine, with flexible branch wires to the lamp, or it may be fed by a set of portable store cells closely connected with it. I will give you an illustration of the *quality* of the light these incandescent lamps are capable of producing by turning the current from a Siemens' dynamo-electric machine (which is working by means of a gas engine in the basement of the building) through sixty lamps ranged round the front of the gallery and through six on the table. (The theatre was now completely illuminated by means of the lamps, the gas being turned off during the rest of the lecture.)

It is evident by the appearance of the flowers on the table that colours are seen very truly by this light, and this is suggestive of its suitability for the lighting of pictures.

The heat produced is comparatively very small; and of course there are no noxious vapours.

And now I may, I think, fairly say that the difficulties encountered in the construction of incandescent electric lamps have been completely conquered, and that their use is *economically practicable.* In making this statement I mean, that, both as regards the *cost of the lamp* itself and *the cost of supplying electricity to illuminate it,* light can be produced at a cost which will compare not unfavourably with the cost of gas light. It is evident that if this opinion can be sustained, lighting by electricity at once assumes a position of the widest public interest, and of the greatest economic importance; and in view of this, I may be permitted to enter with some detail into a consideration of the facts which support it.

There has now been sufficient experience in the manufacture of lamps to leave no doubt that they can be cheaply constructed, and we know by actual experiment that continuous heating to a fairly high degree of incandescence during 1200 hours does not destroy a well-made lamp. What the utmost limit of a lamp's life may be we really do not know. Probably it will be an ever-increasing span; as, with increasing experience, processes of manufacture are sure to become more and more perfect. Taking it, therefore, as fully established that *a cheap and durable lamp can now be made,* the further question is as to *the cost of the means of its illumination.*

This question in its simplest form is that of the more or less economical use of coal; for coal is the principal raw material alike in the production of gas and of electric light. In the one case, the coal is consumed in producing gas which is burnt, in the other in producing motive power, and, by its means, electricity.

The cost of producing light by means of electric incandescence may be compared with the cost of producing gas-light in this way—2 cwt. of coal produces 1000 cubic feet of gas, and this quantity of gas, of the quality called fifteen-candle gas, will produce 3000 candle-light for one hour. But besides the product of gas, the coal yields certain bye-products of almost equal value. I will, therefore, take it that we have in effect 1000 feet of gas from 1 cwt. of coal instead of from 2, as is actually the case.

And now, as regards the production of electricity. One cwt. of coal—that is the same measure *in point of value* as gives 1000 feet of gas—will give 50 horse-power for one hour. Repeated and reliable experiments show that we can obtain through the medium of incandescent lamps at least 200 candle-light per horse-power per hour. But as there is waste in the conversion of motive power into electricity, and also in the conducting-wires, let us make a liberal deduction of 25 per cent., and take only 150 candle-light as the nett available product of 1 horse-power; then for 50 horse-power (the product of 1 cwt. of coal), we have 7500 candle-light, as against 3000 candle-light from *an equivalent value* of gas. That is to say, two and a half times more light.

There still remains an allowance to be made to cover the cost of the renewal of lamps. There is a parallel expense in connection with gas lighting in the cost of the renewal of gas-burners, gas globes, gas chimnies, &c. I cannot say that I think these charges against gas-lighting will equal the corresponding charges against electric lighting, unless we import into the account—as I think it right to do—the consideration that, without a good deal of expense be incurred in the renewal of burners, and unless minute attention be given, far beyond what is actually given, to all the conditions under which the gas is burned, nothing like the full light product which I have allowed to be obtainable from the burning of 1000 cubic feet of gas, will be obtained, and, as a matter of fact, is not commonly obtained, especially in domestic lighting. Taking this into account, and considering what would have to be done to obtain the full yield of light from gas, and that if it be not done, then the estimate I have made is too favourable, I think but little, if any, greater allowance need be made for the charge in connection with the renewal of lamps in electric lighting than ought to be made for the corresponding charges for the renewal of gas-burners, globes, chimneys, &c. But it will be seen that even if the cost for renewal of lamps should prove to be considerably greater than the corresponding expense in the case of gas, there is a wide margin to meet them before we have reached the limit of the cost of gas-lighting.

I think too it must be fairly taken into account and placed to the credit of electric lighting, that by this mode of lighting there is entire avoidance of the damage to furnishings and decorations of houses, to books, pictures, and to goods in shops, which is caused through lighting by gas, and which entails a large expenditure for repair, and a large amount of loss which is irreparable.

I have based these computations of cost of electric light on the supposition that the light product of 1 horse-power is 150 candles. But if durability of the lamps had not to be considered, and it were an abstract question how much light can be obtained through the medium of an incandescent filament of carbon, then one might, without deviating from ascertained fact, have spoken of a very much larger amount of light as obtainable by this expenditure of motive power. I might have assumed double or even more than double the light for this expenditure. Certainly double and treble the result I have supposed can actually be obtained. The figures I have taken are those which consist with long life to the lamps. If we take more light for a given expenditure of power, we shall have to renew the lamps oftener, and so what we gain in one way we lose in another. But it is extremely probable that a higher degree of incandescence than that on which I have based my calculations of cost, may prove to be compatible with durability of the lamps. In that case, the economy of electric lighting will be greater than I have stated.

In comparing the cost of producing light by gas and by electricity, I have only dealt with the radical item of coal in both cases. Gas-lighting is entirely dependent upon coal—electric lighting is not, but in all probability coal will be the chief source of energy in the electric lighting also. When, however, water

power is available, electric lighting is in a position of still greater advantage, and, in point of cost, altogether beyond comparison with other means of producing light.

To complete the comparison between the cost of electric light and gas light, we must consider not only the amount of coal required to yield a certain product of light in the one case and in the other, but also the cost of converting the coal into electric current and into gas; that is to say, the cost of manufacture of electricity and the cost of manufacture of gas. I cannot speak with the same exactness of detail on this point as I did on the comparative cost of the raw material. But if you consider the nature of the process of gas manufacture, and that it is a process, in so far as the lifting of coal by manual labour is concerned, not very unlike the stoking of a steam boiler, and if electricity is generated by means of steam, then the manual labour chiefly involved in both processes is not unlike. It is evident that in gas manufacture it would be necessary to shovel into the furnaces and retorts five or six times as much coal to yield the same light product as would be obtainable through the steam engine and incandescent lamps. But here again it is necessary to allow for the value of the labour in connection with the products other than gas, and hence it is right to cut down the difference I have mentioned to half—*i.e.* debit gas with only half the cost of manufacture, in the same way as in our calculation we have charged gas with only one-half the coal actually used. But when that is done there is still a difference of probably three to one in respect of labour in favour of electric lighting.

I have made these large allowances of material and labour in favour of the cost of gas, but it is well known that the bye products are but rarely of the value I have assumed. I desire, however, to allow all that can be claimed for gas.

With regard to the COST OF PLANT, I think there will be a more even balance in the two cases. In a gasworks you have retorts and furnaces, purifying chambers and gasometers, engines, boilers, and appliances for distributing the gas and regulating its pressure. Plant for generating electricity on a large scale would consist principally of boilers, steam-engines, dynamo-electric machines, and batteries for storage.

No such electrical station, on the scale and in the complete form I am supposing, has yet been put into actual operation; but several small stations for the manufacture of electricity already exist in England, and a large station designed by Mr. Edison is, if I am rightly informed, almost completed in America. We are therefore on the point of ascertaining by actual experience, what the *cost of the works* for generating electricity will be. Meanwhile, we know precisely the cost of boilers and engines, and we know approximately what ought to be the cost of dynamo-electric machines of suitably large size. We have, therefore, sufficient grounds for concluding that to produce a given quantity of light electrically the cost of plant would not exceed greatly, if at all, the cost of equivalent gas-plant.

There remains to be considered, in connection with this part of the subject, the *cost of distribution*. Can electricity be distributed as widely and cheaply as gas? On one condition, which I fully hope can be complied with, this may be answered in the affirmative. The condition is that it may be found practicable and safe to distribute electricity of comparatively high tension.

The importance of this condition will be understood when it is remembered that to effectively utilise electricity in the production of light in the manner I have been explaining, it is necessary that the *resistance in the carbon of the lamps* should be relatively great to the *resistance in the wires which convey the current to them*. When lamps are so united with the conducting wire, that the current which it conveys is divided amongst them, you have a condition of things in which the aggregate resistance of the lamps will be very small, and the conducting wire, to have a relatively small resistance, must either be *very short*, or, if it be long, it must be *very thick*, otherwise there will be excessive waste of energy; in fact, it will not be a practical condition of things.

In order to supply the current to the lamps economically, there should be comparatively little resistance in the line. A waste of energy through the resistance of the wire of 10 or perhaps 20 per cent. might be allowable, but if the current is supplied to the lamps in the manner I have described—that of *multiple arc*, each lamp being as it were *a crossing between two main wires*, then—and even if the individual lamps offered a somewhat higher degree of resistance than the lamps now in actual use—the thickness of the conductor would become excessive if the line was far extended. In a line of half a mile, for instance, the weight of copper in the conductor would become so great, in proportion to the number of lamps supplied through it, as to be a serious charge on the light. On the other hand, if a smaller conducting wire were used, the waste of energy and consequent cost would greatly exceed that I have mentioned as the permissive limit.

Distribution in this manner has the merit of simplicity, it involves no danger to life from accidental shock; and it does not demand great care in the insulation of the conductor. But it has the great defect of limiting within comparatively small bounds the area over which the power for lighting could be distributed from one centre. In order to light a large town electrically on this system, it would be necessary to have a number of supply stations, perhaps half a mile or a mile apart. It is evidently desirable to be able to effect a wider distribution than this, and I hope that either by arranging the lamps *in series*, so that the same current passes through several lamps in succession, or by means of *secondary voltaic cells*, placed as electric reservoirs in each house, it may be possible to economically obtain a much wider distribution.

Whether by the method of multiple arc (illustrated by Diagram I.) which necessitates the multiplication of electrical stations; or by means of the simple series (illustrated by Diagram II.), or by means of secondary batteries connected with each other from house to house in single series, the lamps being fed from these in multiple arc (as illustrated by Diagram III.), I am quite satisfied that comparatively with the distribution of gas, the distribution of electricity is sufficiently economical to permit of its practical application on a large scale.

As to the cost of laying wires in a house, I have it on the authority of Sir Wm. Thomson, who has just had his house completely fitted with incandescent lamps from attics to cellars—to the entire banishment of gas—that the cost of internal wires for the electric lamps is less than the cost of plumbing in connection with gas-pipes.

I have expended an amount of time on the question of *cost* which I fear must have been tedious; but I have done so from the conviction that the practical interest of the matter depends on this point. If electric lighting by incandescence is not an economical process, it is unimportant; but if it can be established—and I have no doubt that it can—that this mode of producing light is economical, the subject assumes an aspect of the greatest importance.

Although at the present moment there may be deficiencies in the apparatus for generating and storing electricity on a very large scale, and but little experience in distributing it for lighting purposes over wide areas, and consequently much yet to be learnt in these respects; yet, if once it can be clearly established that, light for light, electricity is as cheap as gas, and that it can be made applicable to all the purposes for which artificial light is required, electric light possesses such marked advantages in connection with health, with the preservation of property, and in respect of safety, as to leave it as nearly certain as anything in this world can be, that the wide substitution of the one form of light for the other is only a question of time.

SCIENTIFIC SERIALS

Bulletin de l'Academie Royale des Sciences de Belgique, No. 6. —Resistance of the air in guns; letter by M. Colladon.—Note on experimental ballistics, by M. Melsens.—Experimental rerearches on the respiratory movements of insects, by M. Plateau. —Existence and amount of diurnal precession and nutation, on the hypothesis of a solid earth, by M. Folie.—Fundamental principle relative to contact of two surfaces having a common generatrix, by M. Mansion.—On a geometrical representation of two uniform transformations, by M. Le Paige.—On bibrominated camphor, by M. Swarts.—Action of trichloride and tribromide of phosphorus on gaseous phosphuretted hydrogen, by M. de Wilde.—Action of trichloride of phosphorus on iodide of phosphonium, by the same.—Researches on the structure and signification of the respiratory apparatus of Arachnida, by Mr. MacLeod.

Annalen der Physik und Chemie, No. 8.—On development of electricity as equivalent of chemical processes, by F. Braun.—The theory of the micro-telephone, by V. Wietlisbach.—On prism-observation with obliquely-incident light, and on a modi-